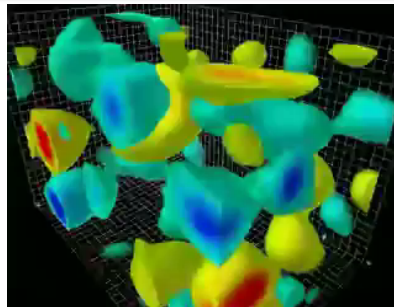




Electron Ion Collider (*An Overview*) & Preliminary Thoughts about ePHENIX

**Precision study & understanding the role of
gluons (& sea quarks) in QCD**

<http://arxiv.org/pdf/1108.1713v1>



Abhay Deshpande

GSI \leftrightarrow BNL Collaboration



Our knowledge of gluons comes (mainly) from scaling violations of F_2 structure function of the proton from HERA.

Extraction based on the assumption that structure functions evolve “linearly”: partonic interactions as if in low density partonic media.

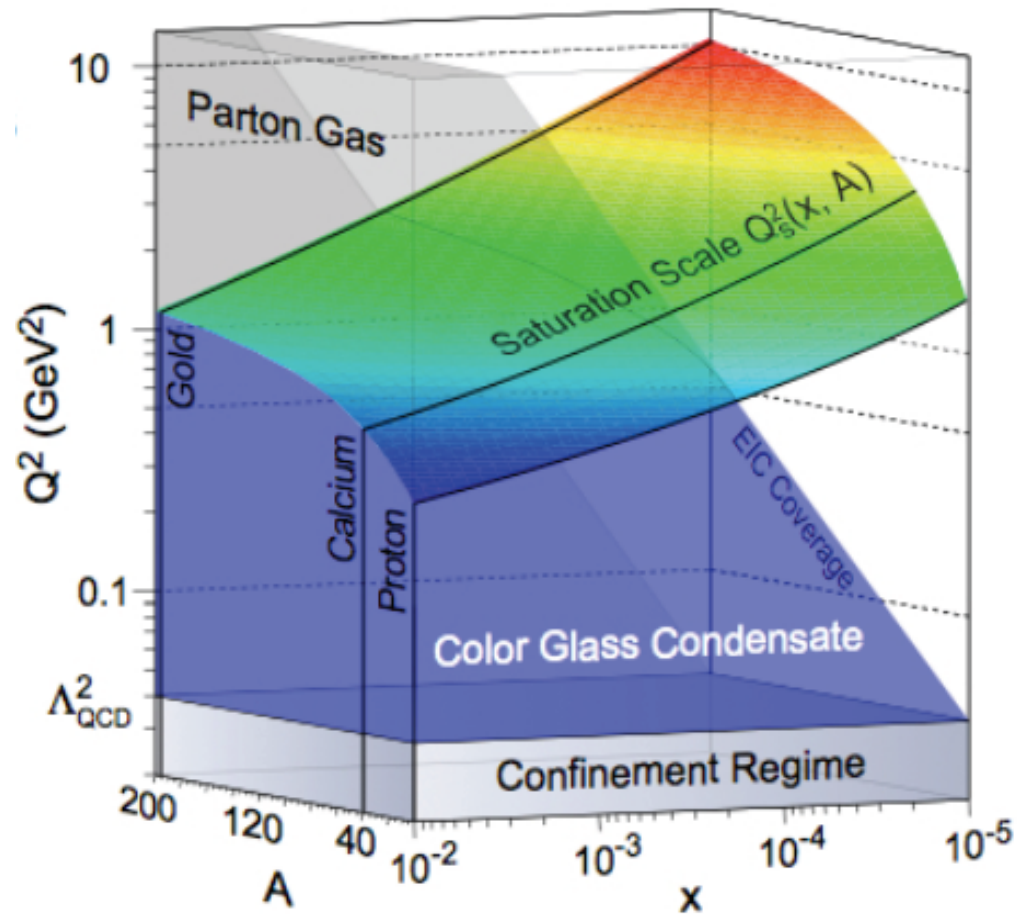
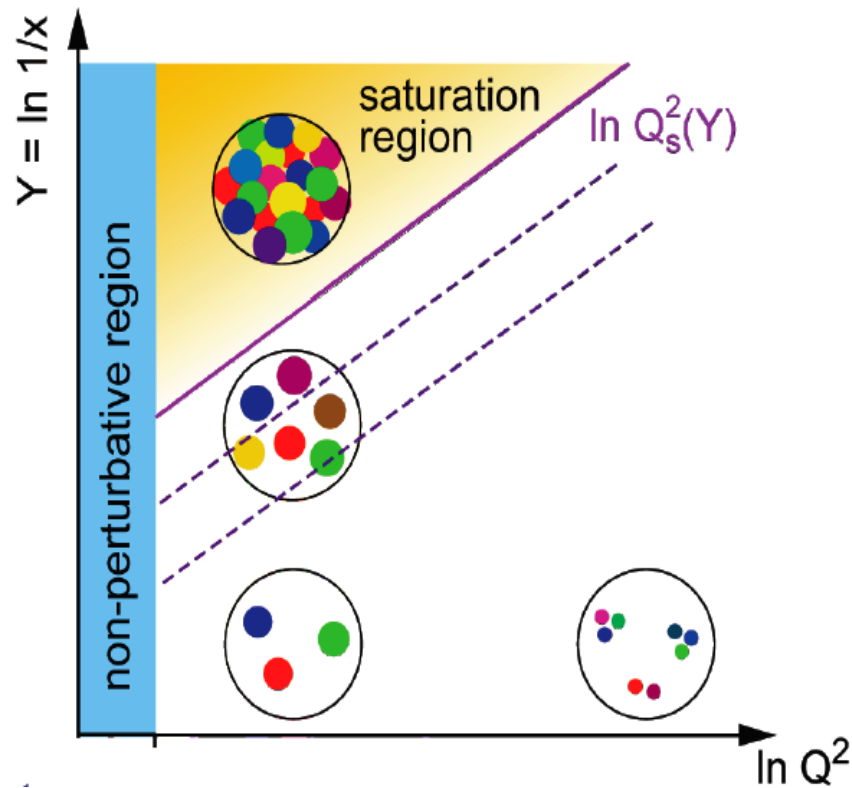
What happens when interactions are “non-linear” at extremely low x ? --Regions of extreme high partonic density.

HOW WELL DO WE UNDERSTAND GLUONS?

Low-x, higher twist & Color Glass Condensate



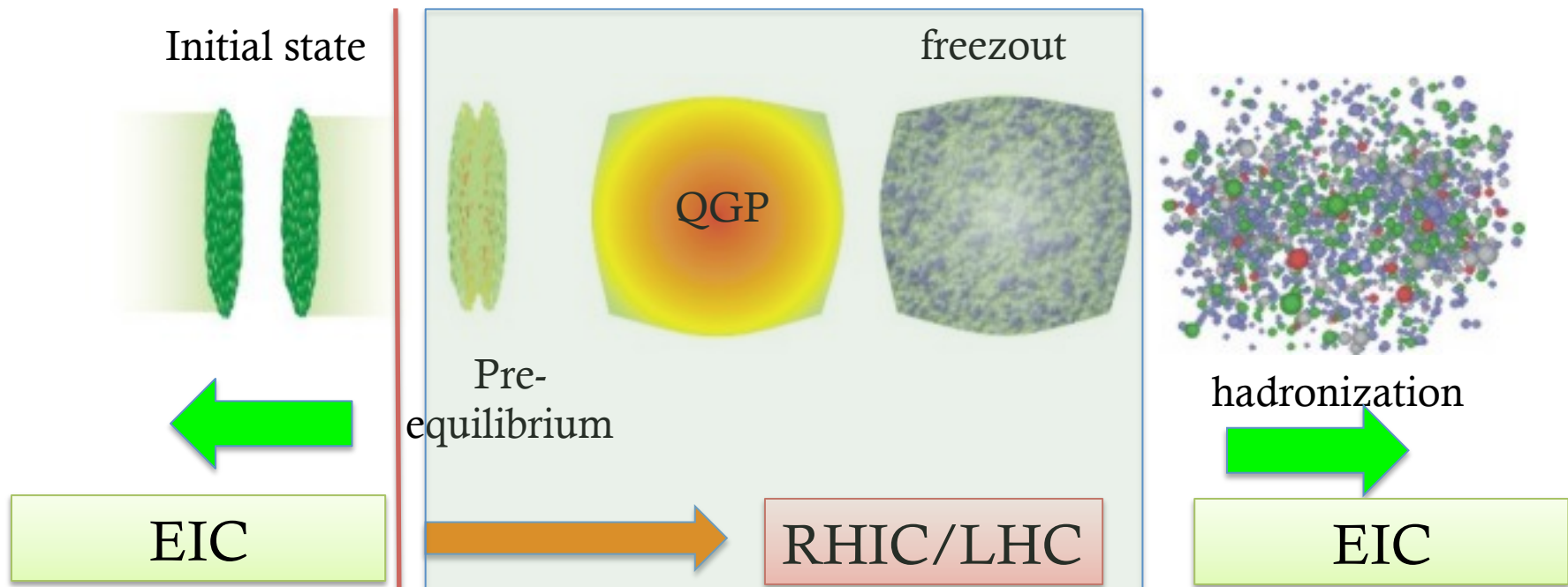
McLerran, Venugopalan... See Review: F. Gelis et al., , arXiv:1002.0333)



Could be explored cleanly in future with a high energy electron-Nucleus Collider



EIC and RHIC/LHC (Heavy Ion)



A decadal plan is being launched to characterize the “QGP”
To understand “QGP” fully, we need to understand:

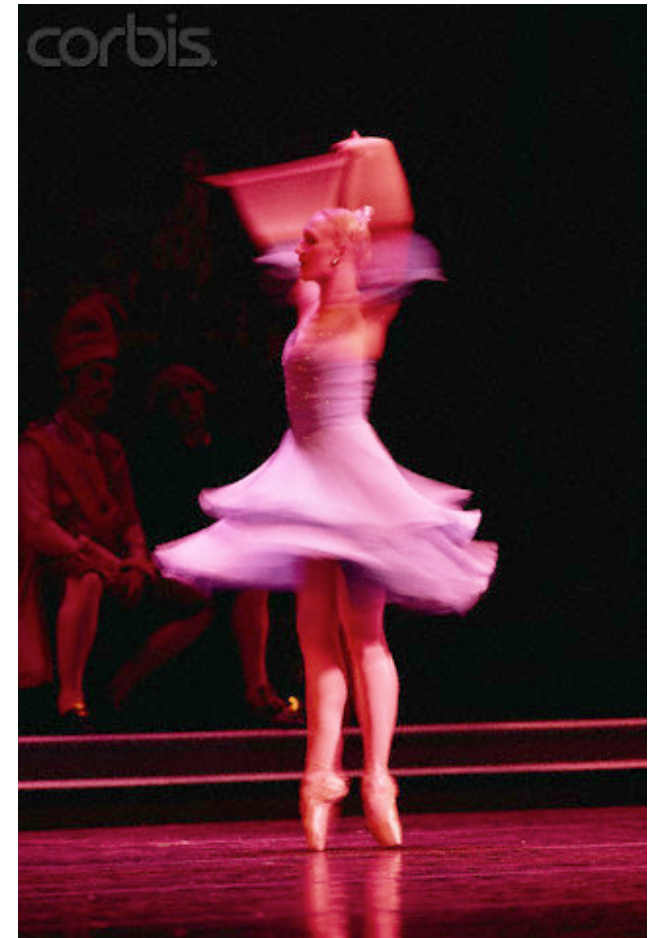
The initial state i.e. the nucleus & hadronization

Deeper Connection: many body interactions of parton in QCD



$$\frac{1}{2} = J_q + J_g = \frac{1}{2}\Delta\Sigma + L_q + \Delta g + L_g$$

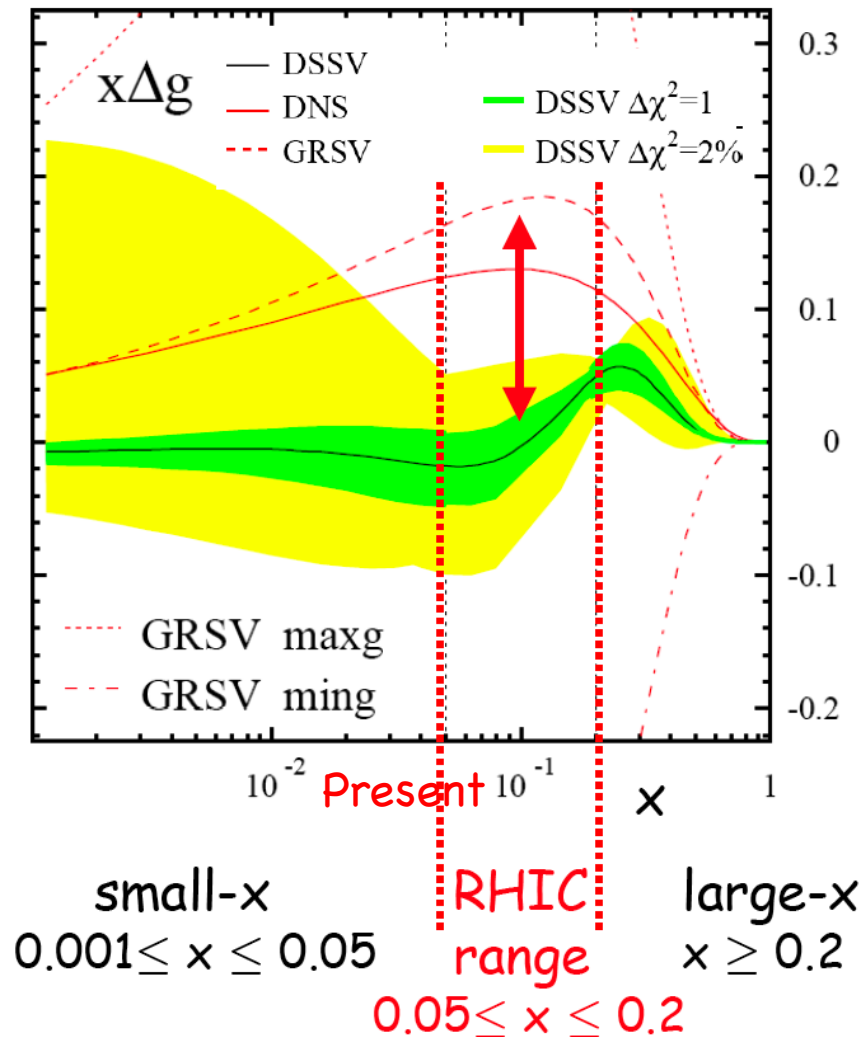
UNDERSTANDING NUCLEON SPIN: WHAT ROLE DO GLUONS PLAY?





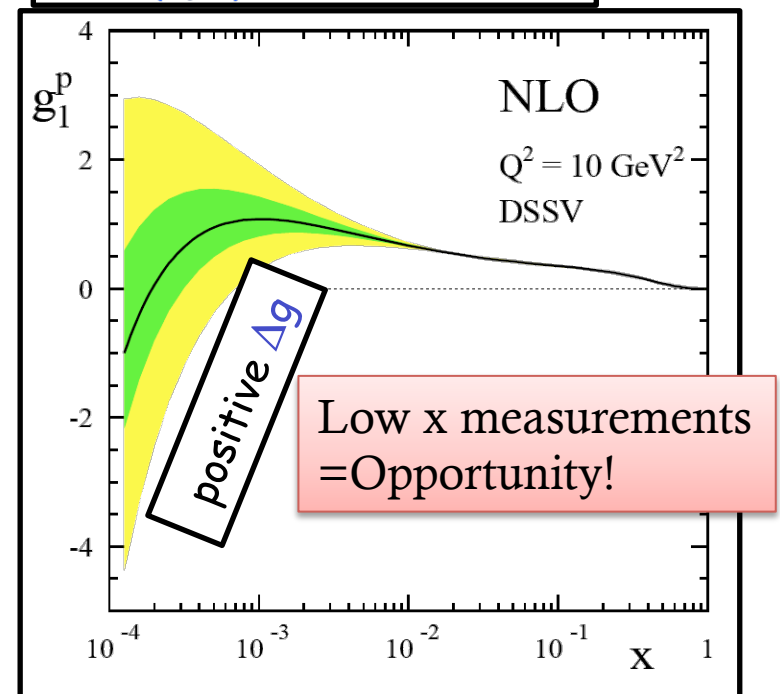
$\Delta g(x) @ Q^2=10 \text{ GeV}^2$

de Florian, Sassot, Stratmann & Vogelsang



- Global analysis: DIS, SIDIS, RHIC-Spin
- Uncertainty on ΔG large at low x

$$\frac{dg_1}{d \log(Q^2)} \propto -\Delta g(x, Q^2)$$



Status of “Nucleon Spin ~~Crisis~~ Puzzle”



$$\frac{1}{2} = J_q + J_g = \frac{1}{2} \Delta\Sigma + L_q + \Delta g + L_g$$

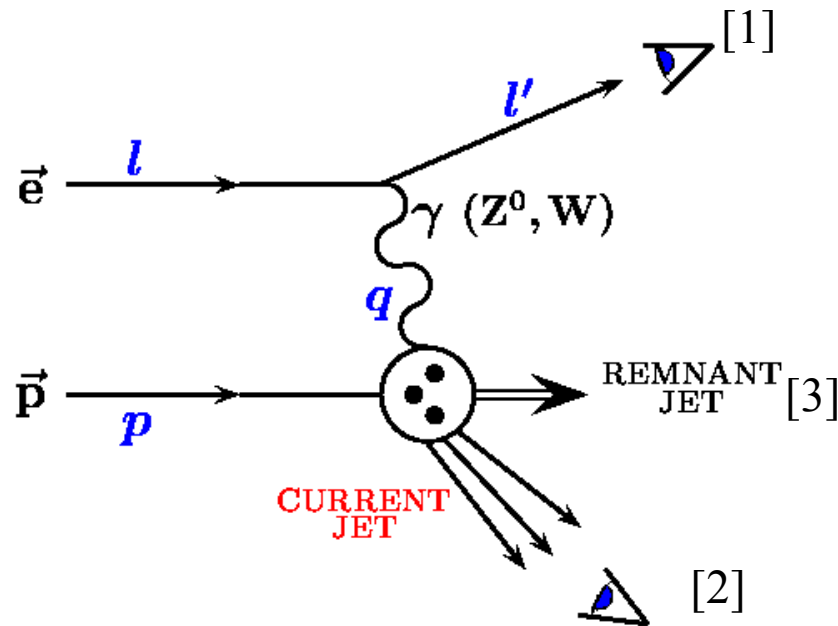
- We know how to measure $\Delta\Sigma$ and ΔG precisely using pQCD
 - $\frac{1}{2} (\Delta\Sigma) \sim 0.15$: From fixed target pol. DIS experiments
 - RHIC-Spin: ΔG *not large* as anticipated in the 1990s, but *measurements & precision needed at low & high x*
- Generalized Parton Distributions: H, E, E', H' \rightarrow Connection to partonic OAM
 - Quark GPDs $\rightarrow J_q$: 12GeV@JLab & COMPASS@CERN
 - *Gluons @ low x $\rightarrow J_g \rightarrow$ will need the future EIC!*
- (2+1)D tomographic image of the proton.... Transverse Mom. Distributions
 - *2: x,y position and +1: momentum in z direction*

Towards full understanding of transverse and longitudinal hadron structure including spin!



The Proposal:

Future DIS experiment at an Electron Ion Collider: A high energy, high luminosity (polarized) ep and eA collider and a suitably designed detector



Measurements:

[1] \rightarrow Inclusive

[1] and [2] or [3] \rightarrow Semi-Inclusive

[1] and [2] and [3] \rightarrow Exclusive

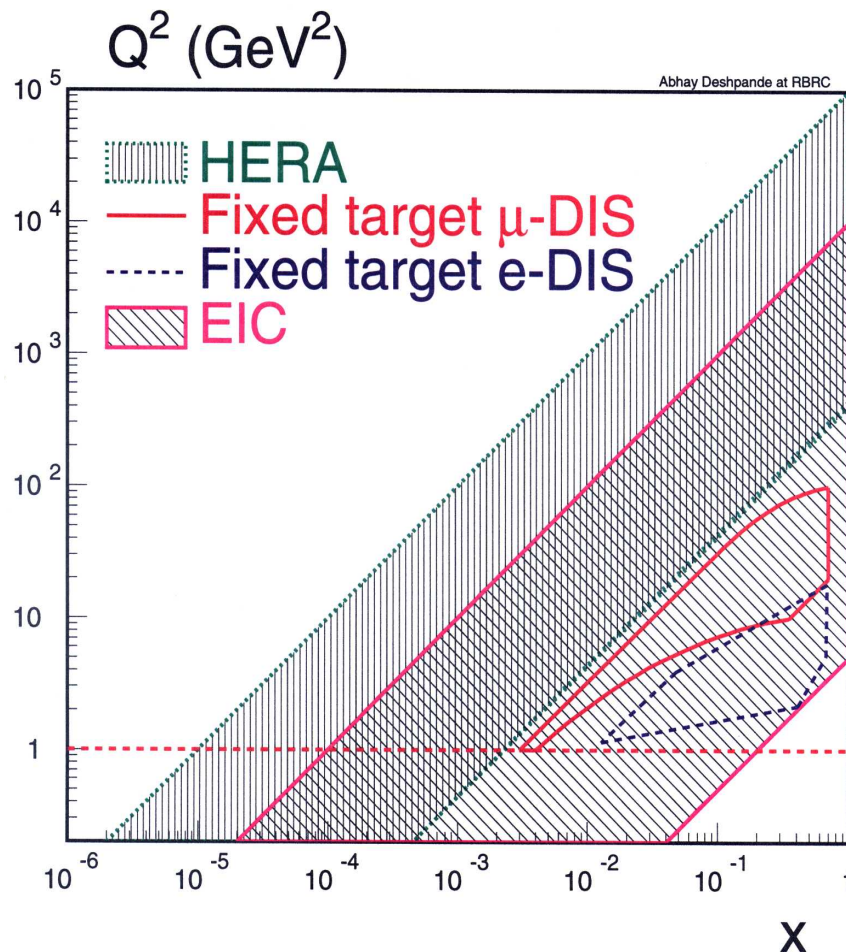
Inclusive \rightarrow Exclusive

Low \rightarrow High Luminosity

Demanding Detector capabilities



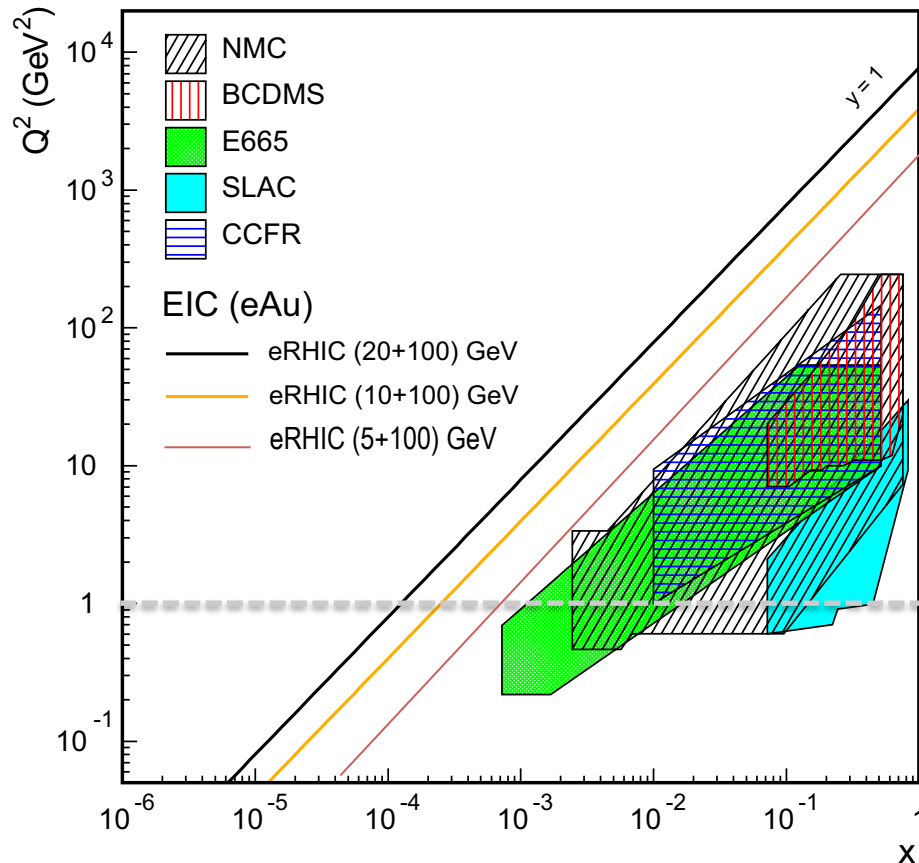
EIC : Basic Parameters (e-p)



- $E_e = 10$ GeV (5-30 GeV variable)
- $E_p = 250$ GeV (50-275 GeV Variable)
- $\text{Sqrt}(S_{ep}) = 100$ (30-180) GeV
- $x_{\min} \sim 10^{-4}$; $Q^2_{\max} \sim 10^4$ GeV
- Polarization $\sim 70\%$: e,p, D/ ^3He
- Luminosity $L_{ep} = 10^{33-34} \text{ cm}^{-2}\text{s}^{-1}$
- Minimum Integrated luminosity:
 - 50 fb^{-1} in 10 yrs (100 x HERA)
 - Possible with $10^{33} \text{ cm}^{-2}\text{s}^{-1}$
 - Recent projections *much higher*



EIC : Basic Parameters (e-A)



- $E_e = 10$ GeV (5-30 GeV variable)
- $E_A = 100$ GeV (20-110 GeV Variable)
- $\text{Sqrt}(S_{eA}) = 63$ (20-115) GeV
- $x_{\min} \sim 10^{-4}$;
- $Q^2_{\max} \sim 8 \times 10^3$ GeV

Nuclei:

- Proton \rightarrow Uranium
- $L_{eA}/N = 10^{33-34}$ cm⁻²s⁻¹



Machine Designs

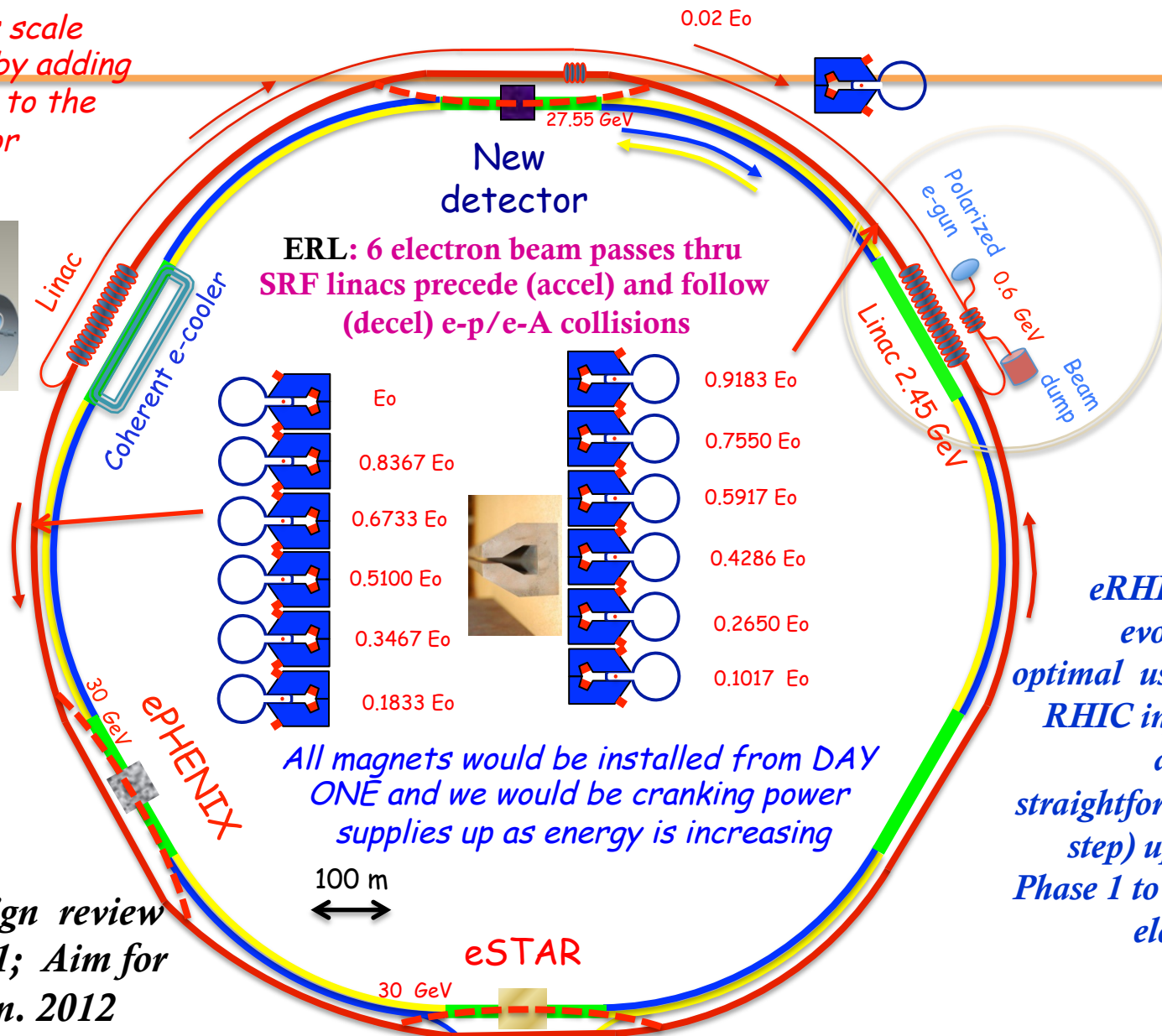
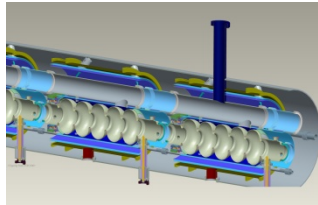
eRHIC at Brookhaven National Laboratory
using the existing RHIC complex

ELIC at Jefferson Laboratory using the
Upgraded 12GeV CEBAF

Both planned to be STAGED

Staging of eRHIC: $E_0 : 5 \rightarrow 30 \text{ GeV}$

All energies scale proportionally by adding SRF cavities to the injector



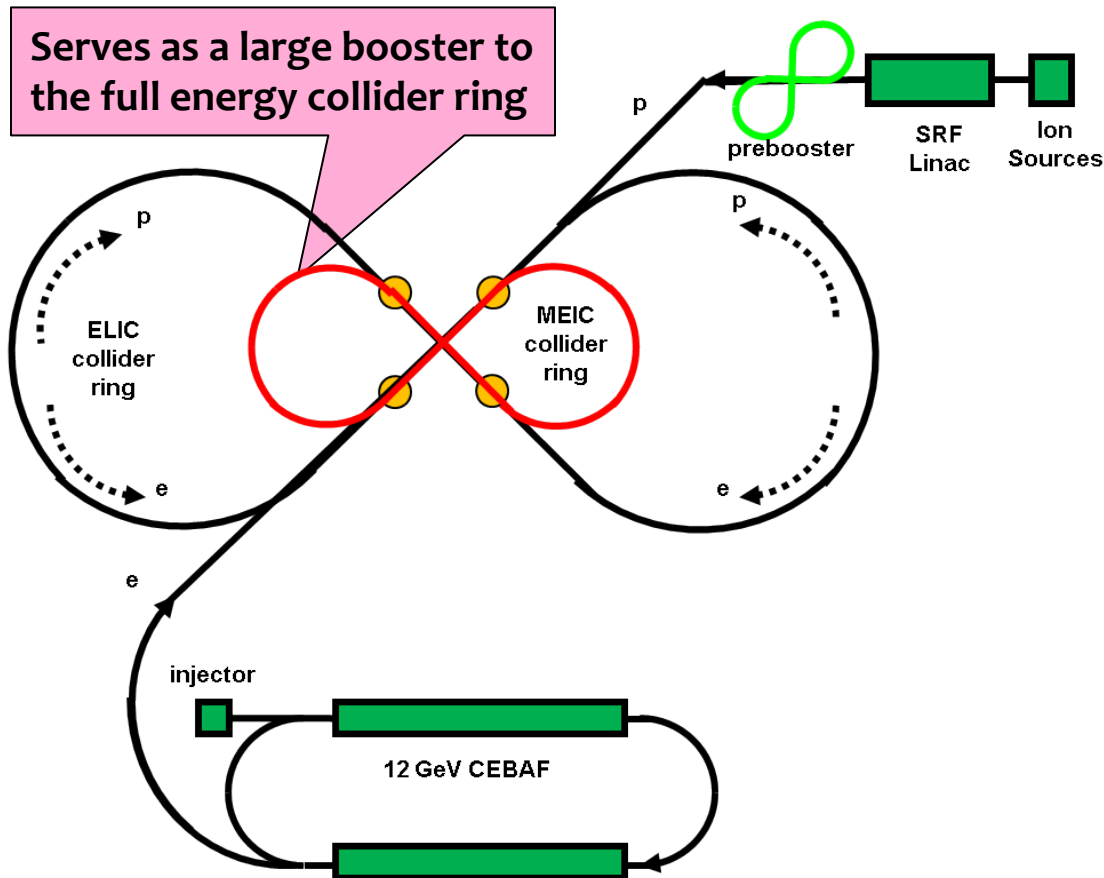
E/E_0
0.0200
0.1017
0.1833
0.2650
0.3467
0.4283
0.5100
0.5917
0.6733
0.7550
0.8367
0.9183
1.0000

eRHIC design has evolved to make optimal use of existing RHIC infrastructure, and to permit straightforward (multi-step) upgrades from Phase 1 to eventual full electron energy

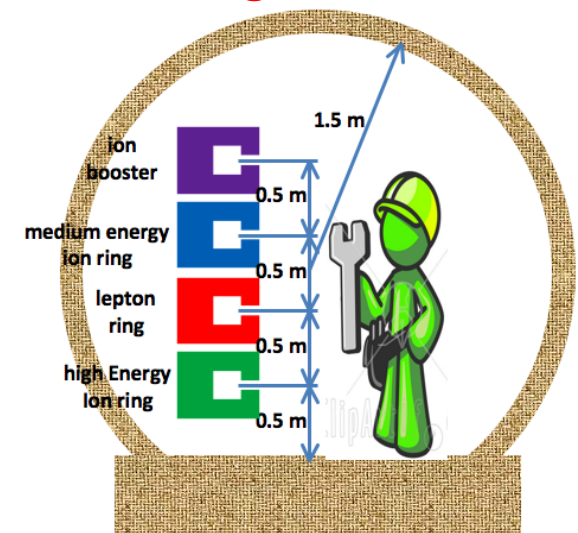
*Technical design review
Aug. 1-3, 2011; Aim for
cost review Jan. 2012*



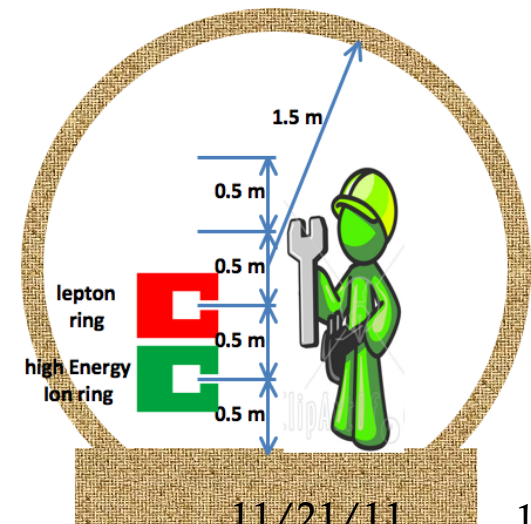
ELIC at Jefferson Lab: High Energy & Staging



Straight section



Arc



Stage	Max. Energy (GeV/c)		Ring Size (m)	Ring Type		IP #
	p	e		p	e	
Medium	96	11	1000	Cold	Warm	3
High	250	20	2500	Cold	Warm	4



high acceptance $-5 < \eta < 5$ central detector
good PID and vertex resolution ($< 5\mu\text{m}$)
tracking and calorimeter coverage the same \rightarrow good momentum resolution, lepton PID
low material density \rightarrow minimal multiple scattering and brems-strahlung
very forward electron and proton detection \rightarrow maybe dipole spectrometers



A set of meetings on the Physics of EIC: 1999-2010

<http://web.mit.edu/eicc/Meetings.html>

A series of Users Workshops at Jefferson Lab in 2010:

Users Workshops Organizer by the Users of Jeff Lab:

<http://michael.tunl.duke.edu/workshop>

<http://www.physics.rutgers.edu/np/2010rueic-home.html>

<http://www.phy.anl.gov/mep/EIC-NUC2010/>

https://eic.jlab.org/wiki/index.php/Electroweak_Working_Group

An International Group met at the INT September – December 2010 to define: The Science of EIC “Golden Measurements”

Institute of Nuclear Theory (INT) at U. of Washington: Sep-Nov 2010

Organizers: D. Boer, M. Diehl, R. Milner, R. Venugopalan, W. Vogelsang

See the INT WebPage for details of all studies:

<http://www.int.washington.edu/PROGRAMS/10-3/>

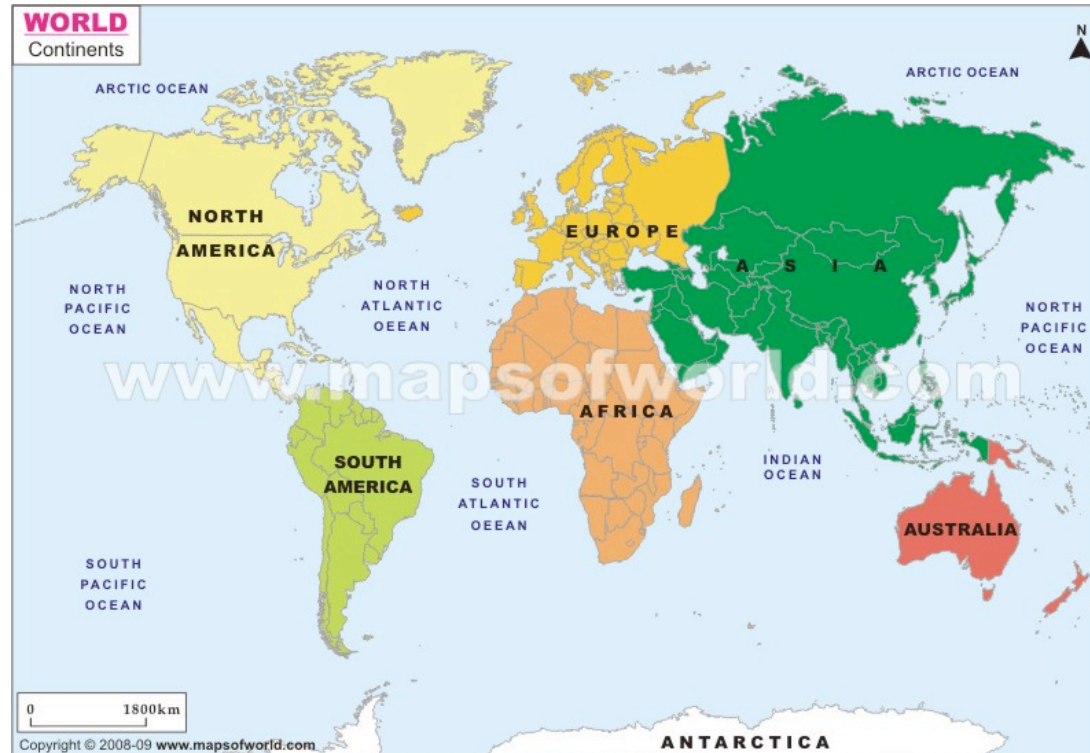
INT Workshop Write-up: <http://arxiv.org/abs/1108.1713>



Science of EIC:

Precise Investigations of the “Glue & Sea Quarks”

- Precision measurements of Sea Quarks and Gluon's Spin via inclusive and semi-inclusive DIS including EW probes of the hadron structure
 - Measurement of (gluon) GPDs & TMDs: via semi-inclusive and exclusive DIS → **wide range in x and Q^2**
 - 3D momentum and position (correlations) of the nucleon
→ **Possibly leading to orbital angular momentum**
 - Study of extreme high gluon densities via inclusive and semi-inclusive DIS off a wide range of nuclei and energies
-
- High energy, beam polarization, and a full acceptance detector: why not explore precision electroweak physics observables & searches of physics beyond the SM



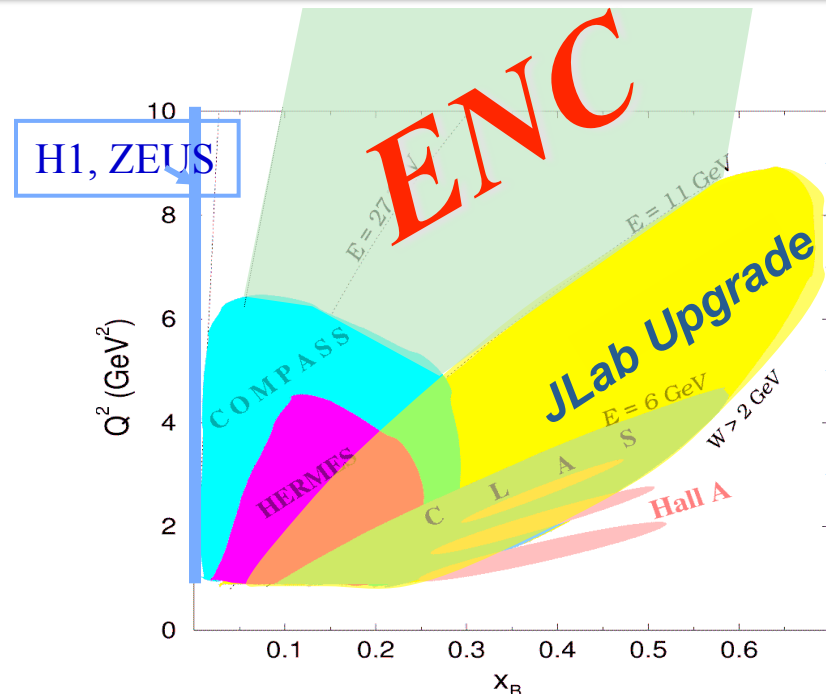
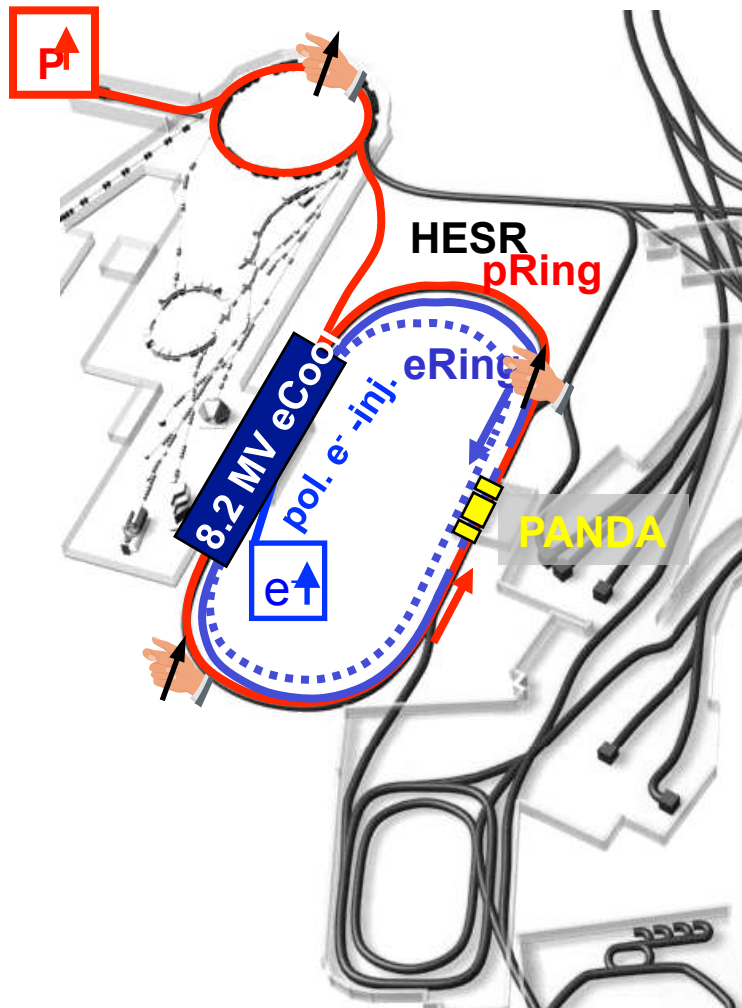
Electron Ion Colliders in Europe...

LHeC & ENC

Transverse spin structure & dynamics in Nucleons



ENC at FAIR



$L > 4 \cdot 10^{32} / \text{cm}^2 \text{s}$

$s^{1/2} > 10 \text{ GeV}$ ($3.3 \text{ GeV } e^- \leftrightarrow 15 \text{ GeV } p$)

polarised e^- (80%)

\leftrightarrow

polarised p / d (80%)
(transversal + longitudinal)

Principle focus: **GPDs and TMDs**



Science of EIC:

Precise Investigations of the “Glue & Sea Quarks”

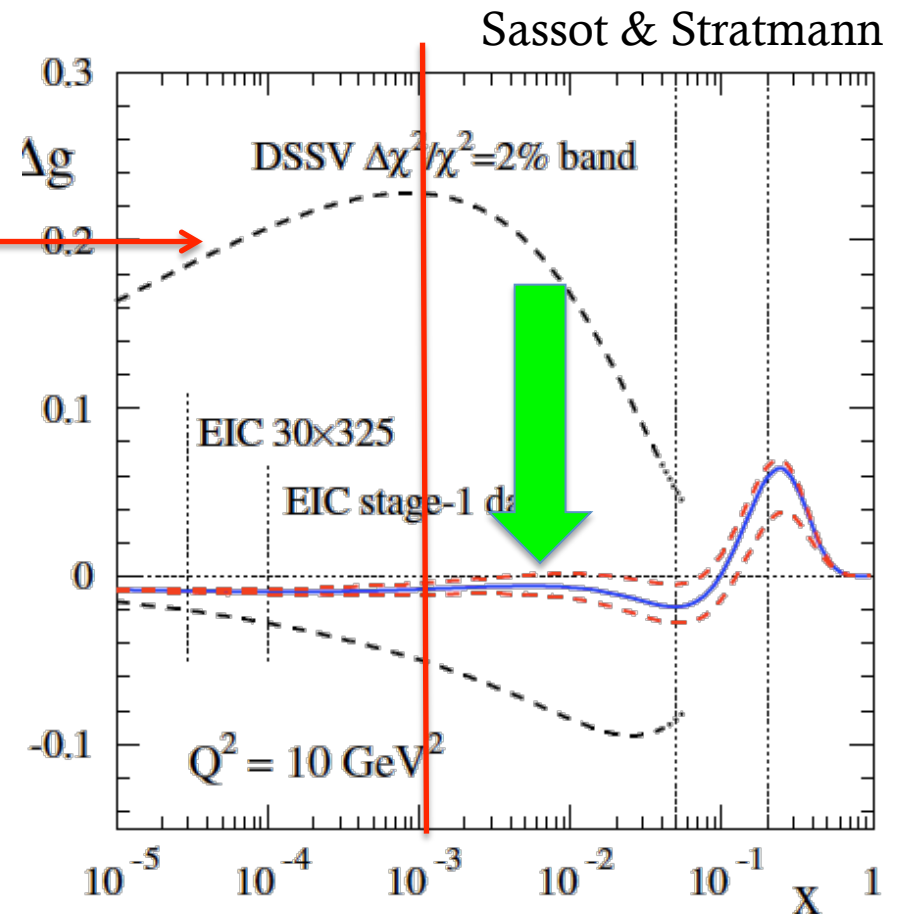
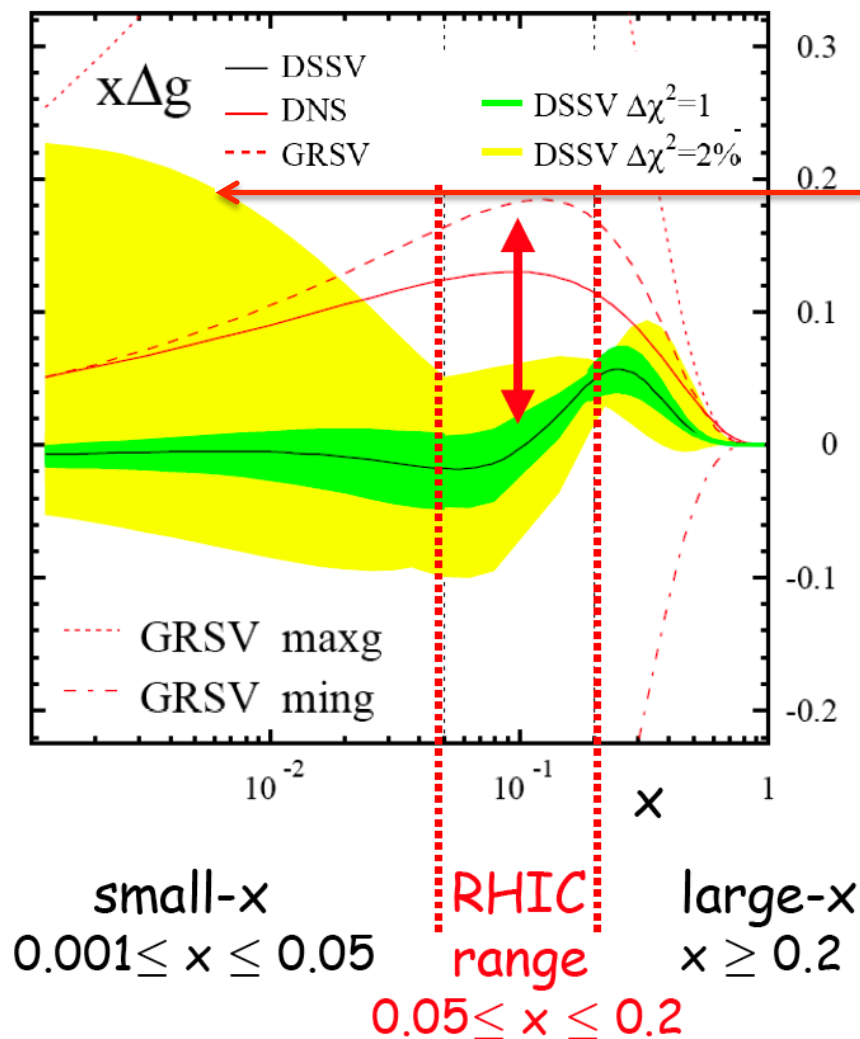
- Precision measurements of Sea Quarks and Gluon's Spin via inclusive and semi-inclusive DIS including EW probes of the hadron structure
- Measurement of (gluon) GPDs & TMDs: via semi-inclusive and exclusive DIS → **wide range in x and Q^2**
 - 3D momentum and position (correlations) of the nucleon
→ Possibly leading to orbital angular momentum
- Study of extreme high gluon densities via inclusive and semi-inclusive DIS off a wide range of nuclei and energies

Science of ENC

-
- High energy, beam polarization, and a full acceptance detector: why not explore precision electroweak physics and EW (spin) structure functions



Nucleon Spin: Precision measurement of ΔG



Yellow band (left) reduces to the band shown with **red dashed line** (right)



Advice for realization

Keep the Total Project Cost < \$500M

Identify compelling physics deliverables

Requires gradual evolution of existing facilities (including the detectors) in to the EIC detector

RHIC (2010) → eRHIC (2020+)

PHENIX/STAR → sPHENIX/STAR++ (2015+)

sPHENIX/STAR++

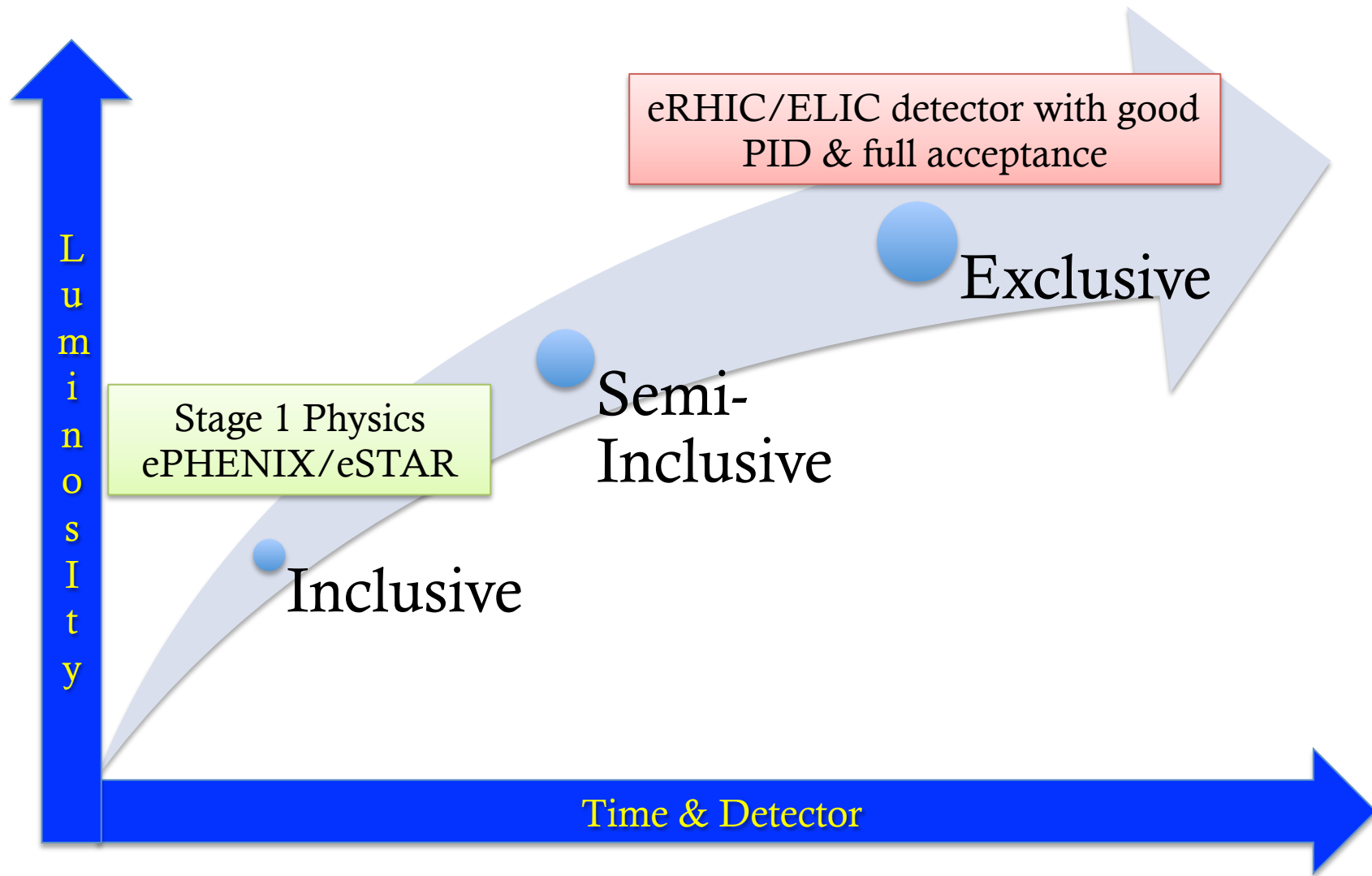
→ ePHENIX/eSTAR (2020+)

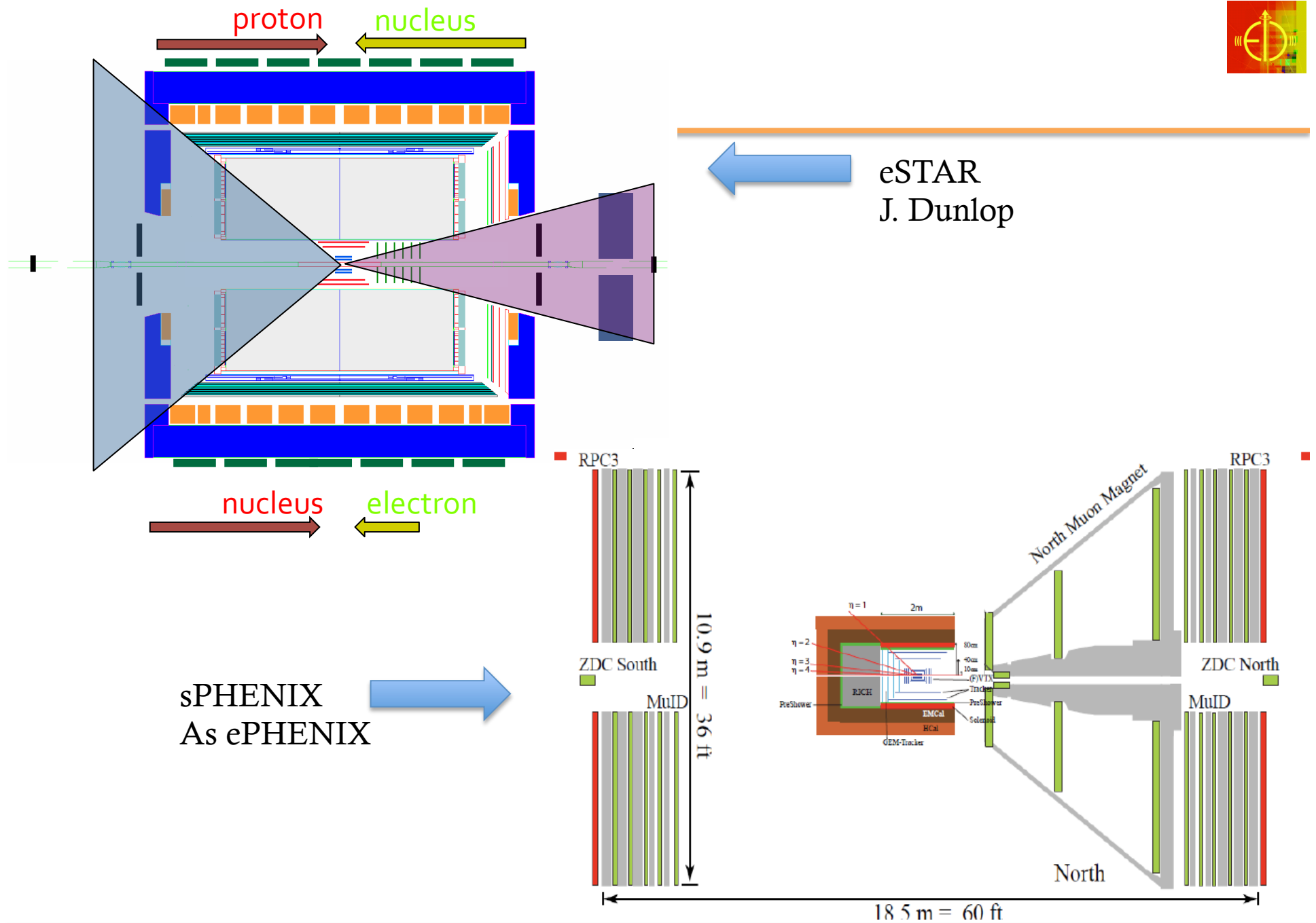
→ eRHIC Detector (2025+?)

STAGED REALIZATION



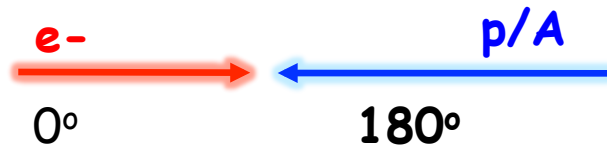
EIC Luminosity vs. Time (Detector)







Some basic facts for DIS measurements

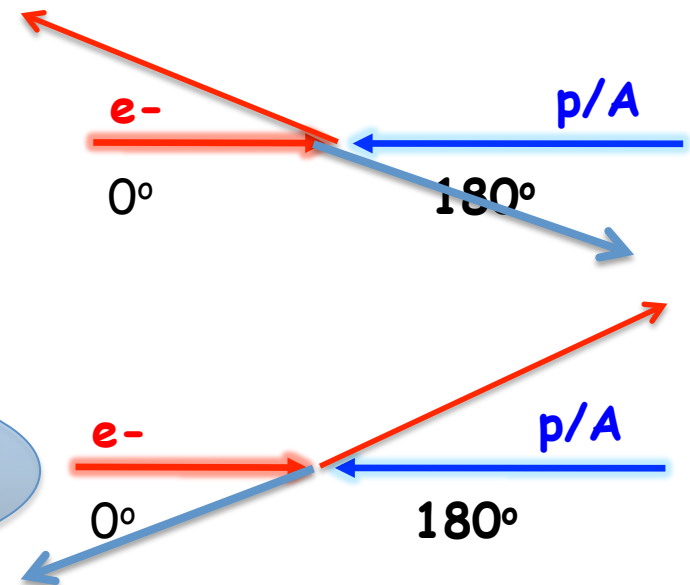
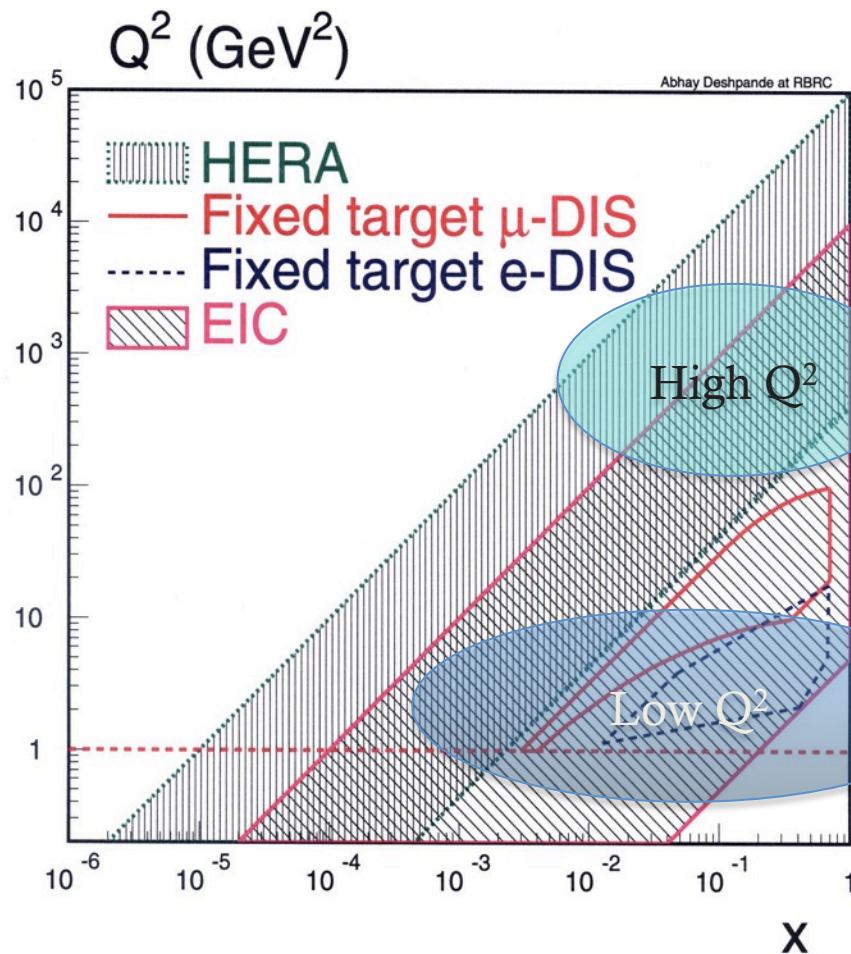


$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$
$$Q^2 = 2E_e E'_e (1 - \cos \Theta_e)$$
$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e} \cos^2 \left(\frac{\theta'_e}{2} \right)$$
$$x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

- CM of collisions moving in hadron direction
- **Glazing collisions (low momentum transfer)**
 - Q^2 Small
 - Small angle scattering: electron keeps going essentially in its original direction and hadron remnants keep going in ITS original direction
- **Violent Collisions (large momentum transfer)**
 - Q^2 Large
 - Large angle scattering, electron and hadronic remnants in central detector or even in the reverse directions
- Resolution in x & Q^2 depends on **how well the scattered lepton is measured**
- **At low momenta multiple scattering & Bremsstrahlung a problem → requires low material**

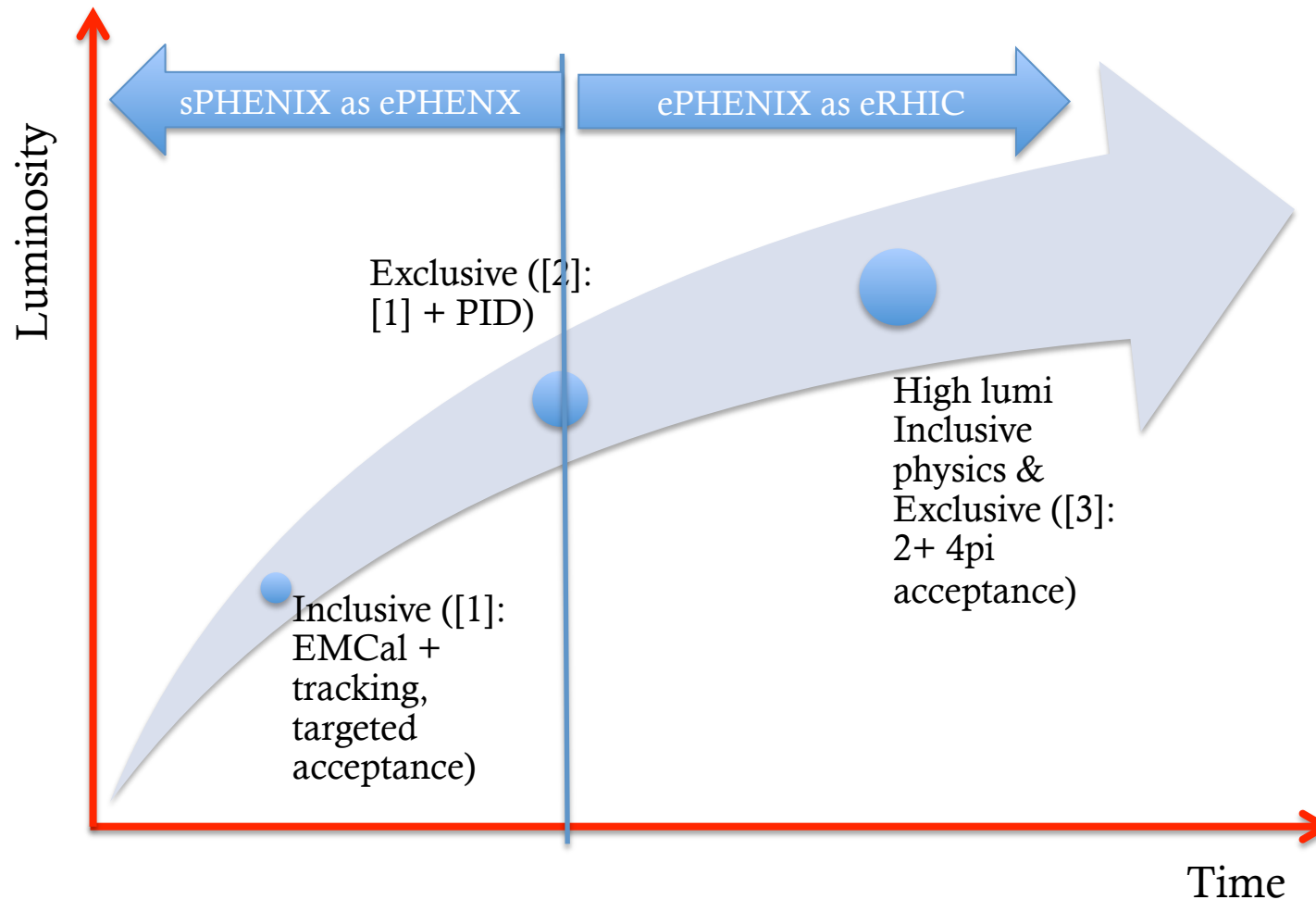


Some geometries...





Time & Luminosity Evolution



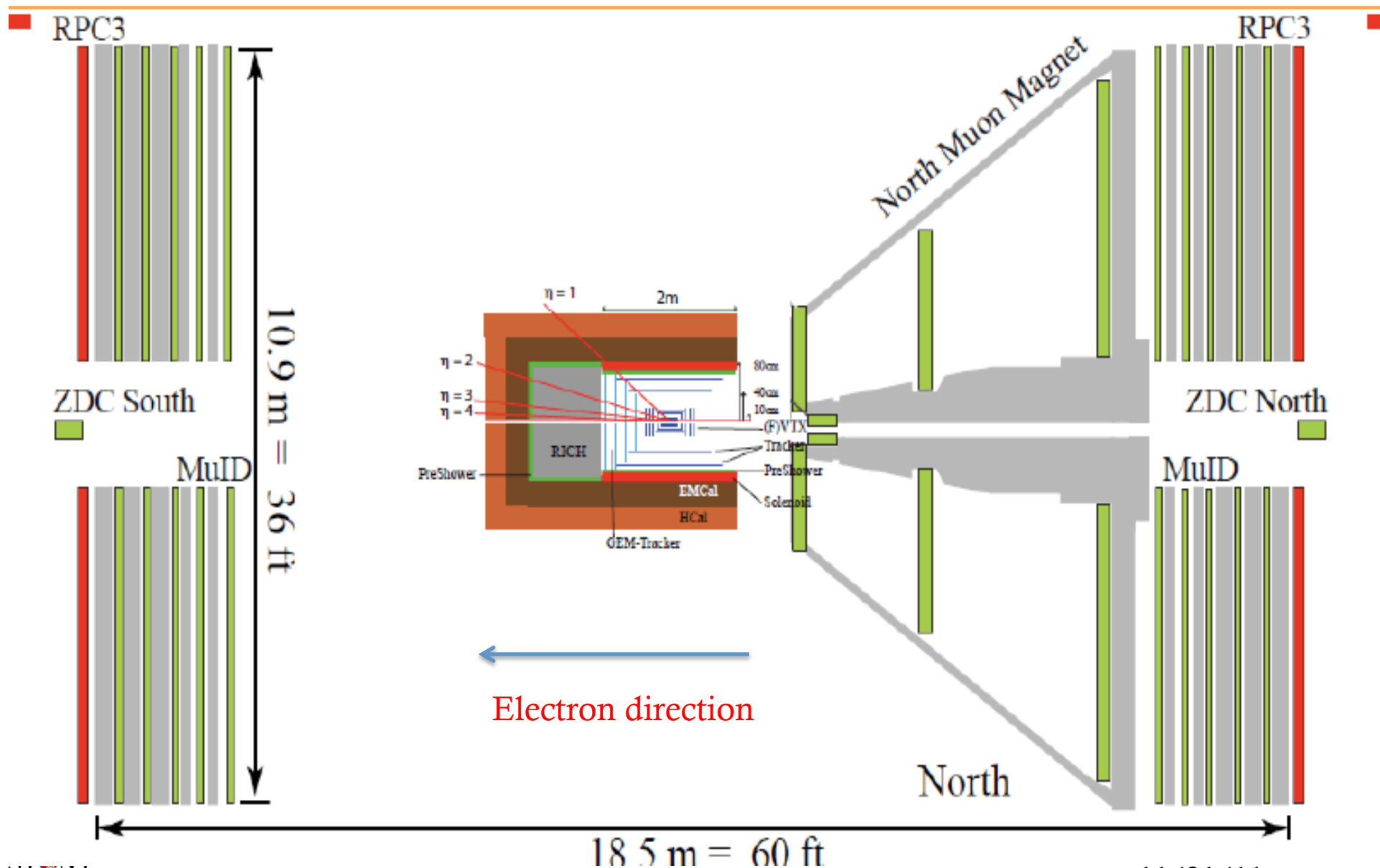


sPHENIX as ePHENIX

- eRHIC (early stage): **ePHENIX should be ready to take**
 - 5-6 GeV electrons + 100-250 GeV nuclei/hadrons
 - Luminosity (low): 5×10^{32} - 10^{33}
 - Physics mainly inclusive, some semi-inclusive:
 - Start investigating low x polarized proton & nuclei
- ePHENIX should be ready for low-mid Q^2 , low-x
 - Calorimetry in electron (backward) direction (-ve η)
 - Low mass tracking in backward and central acceptance
 - PID in the forward & central arm
 - If not at the beginning, **then it should be in the plan**
 - Magnetic field:
 - Solenoid (~ 2 -3 T?), about ~ 1 -1.5m radius considered so far
 - Bore large enough (high cost?) to for PID in future
 - Forward and backward regions dipoles

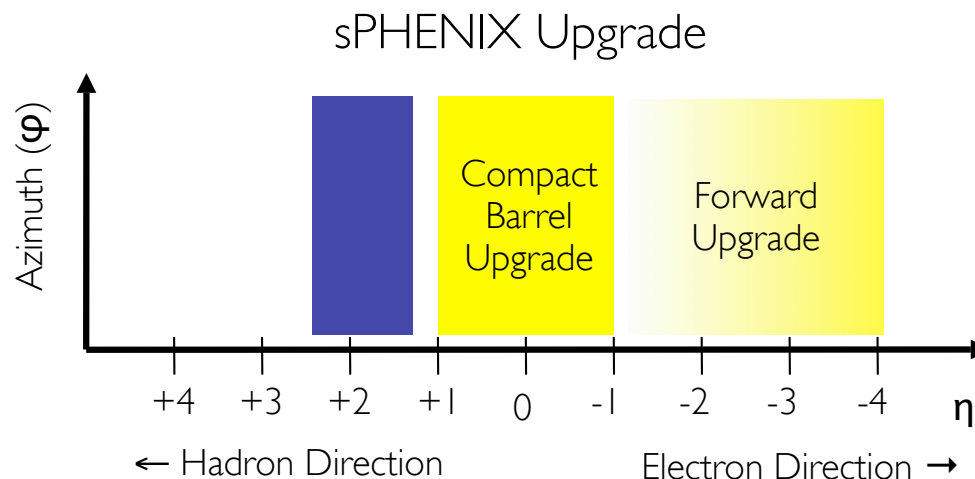
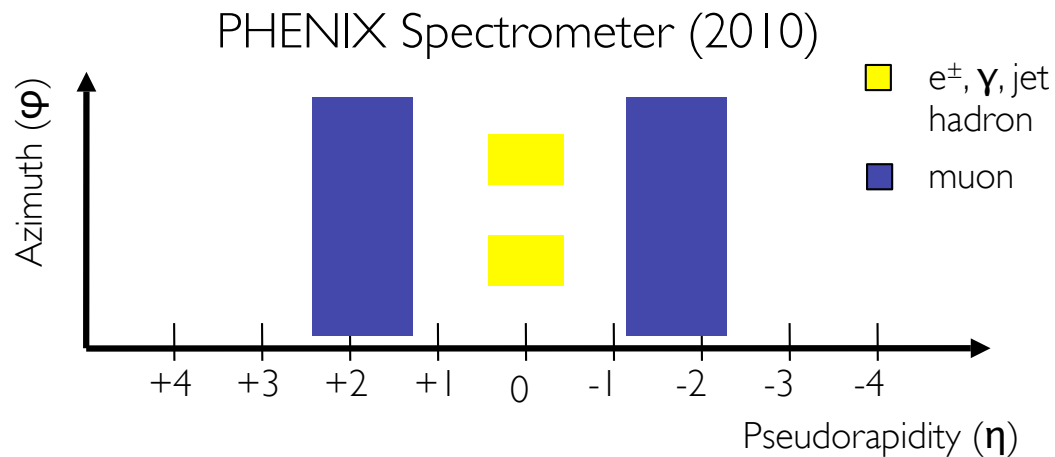


The sPHENIX





EMCal Coverage for sPHENIX



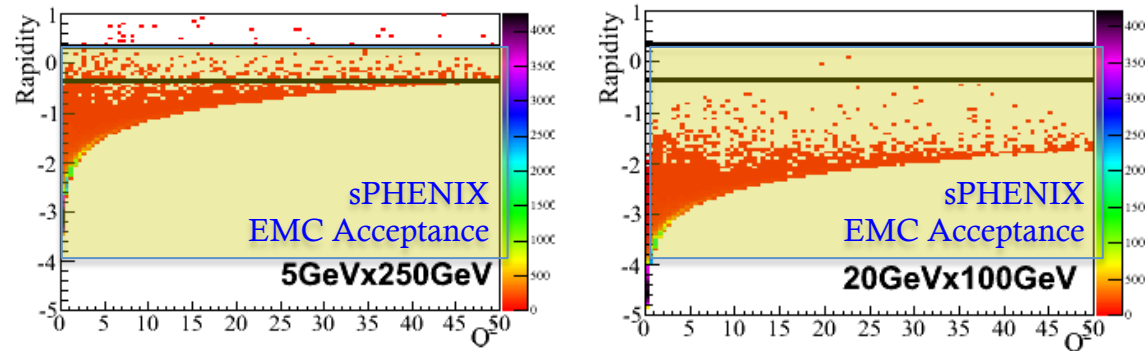
Good for low Q^2 ,
Low x physics
Assuming $\eta \sim -4$ to $+1$
Planned EM Cal coverage

Low material budget?
-Absolute must for 1st eRHIC collisions.

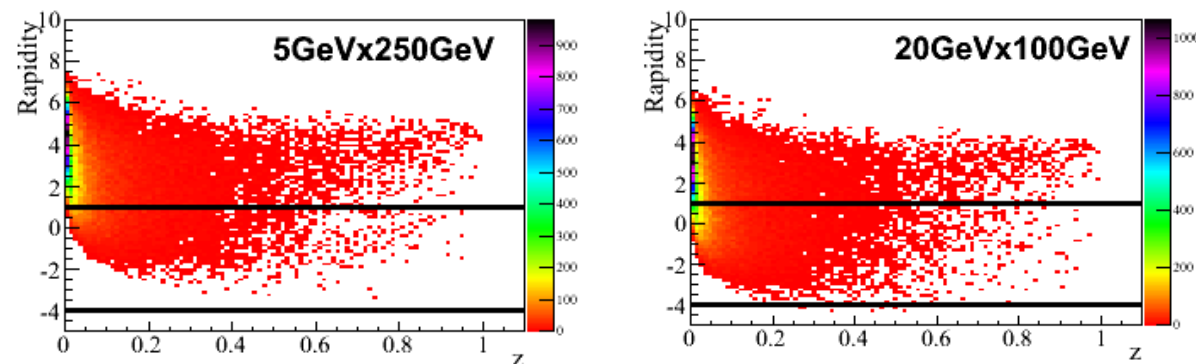


sPHENIX as ePHENIX

- Scattered electrons at different energy combinations



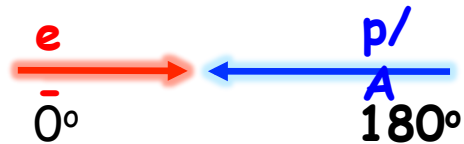
- Pions generated in e-p collisions: (kaons etc. similar) need PID



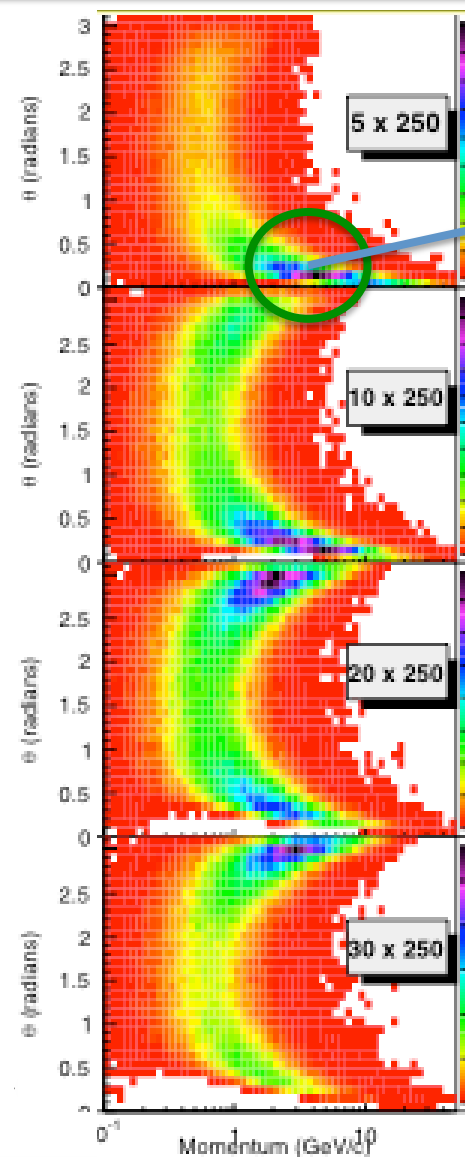
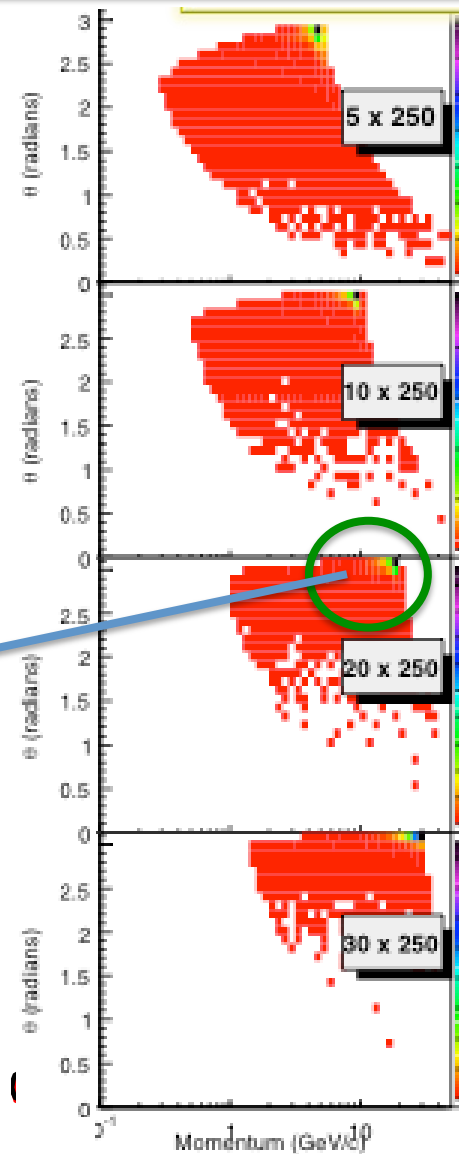
- sPHENIX acceptance: $-4 < \eta < +1$



Electrons and Pions



Close to
 180°



Close to
 0°



Physics with sPHENIX as ePHENIX

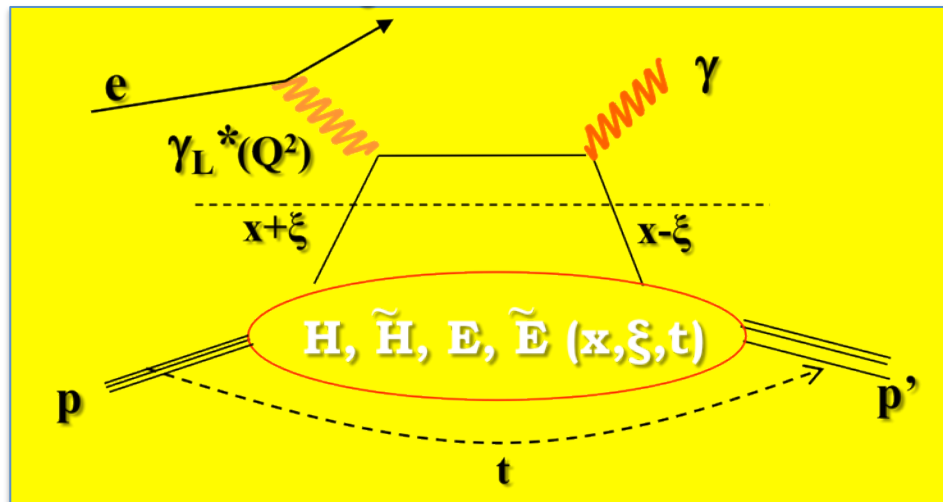
Four major themes emerged from the INT workshop

- Spin & flavor structure of the proton
 - ΔG at low x , Sea Quarks: ΔQ & ΔQ_{bar} (SIDIS), Novel EW SFs
- Three dimensional momentum & position structure of the nucleons and nuclei in momentum and configuration space
 - TMDs and GPDs: momentum correlated spatial imaging
- (Extreme) QCD matter in Nuclei
 - Study of saturation: non-linear QCD evolution, parton energy loss in nuclear media → Learn Detection issues
- Electroweak physics and the searches of physics beyond the SM
 - Weak mixing angle (PV in DIS), lepton flavor violation studies ($e\tau$)



Exclusive Vector Meson Production

$$e+A/p \rightarrow e' + p'/A' + (\gamma, J/\Psi, \phi, \rho)$$



Either measure ALL final products through their decay products

Or

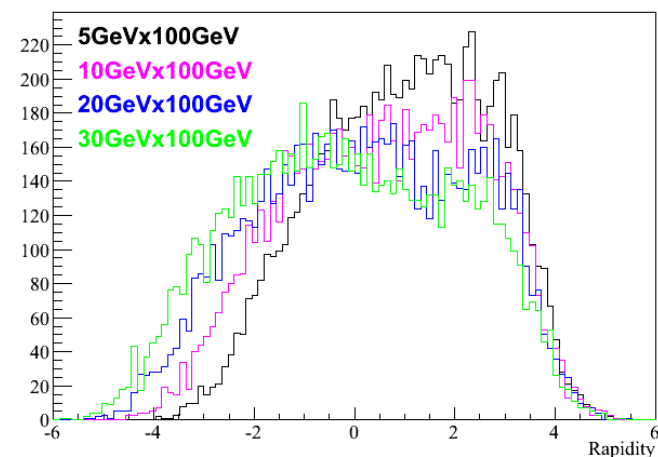
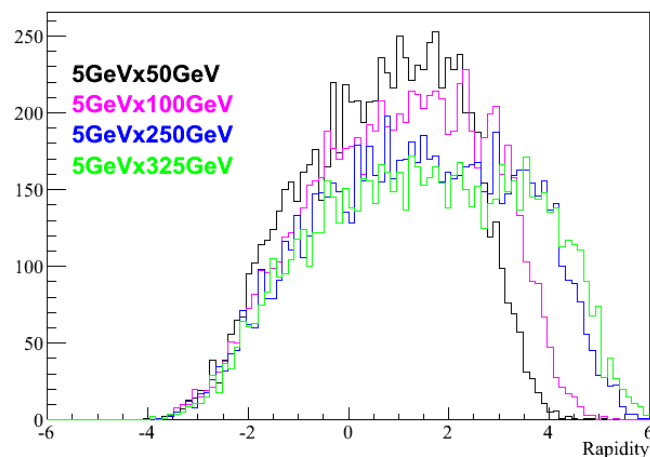
Measure rapidity gap events:
Miss the scattered proton but measure the scattered electron and the vector meson

$$t = (p - p')^2, \xi = \frac{x_B}{2 - x_B}$$



Start some exclusive physics

- Rapidity distribution for pions coming from exclusively produced vector mesons (Rho and J/Psi) for different beam energy combinations

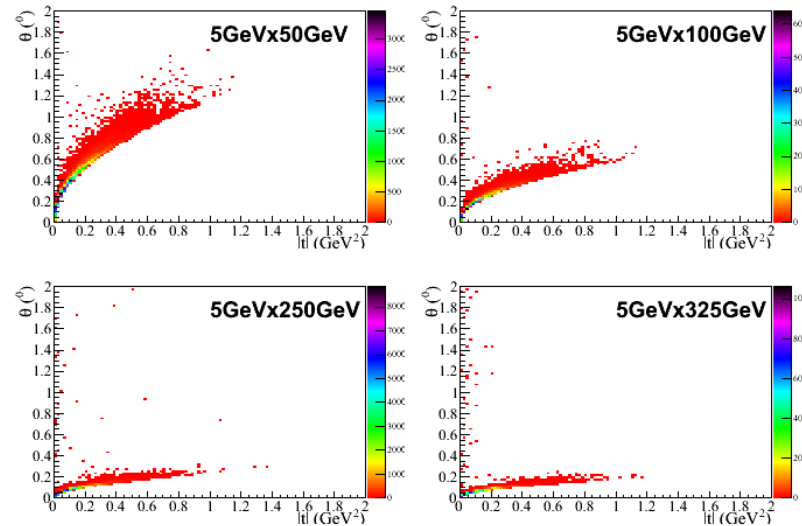


- Particle ID for these measurements necessary over most of the rapidity range
- Initial luminosity may NOT be enough to do this physics, but it will start the program



Elastic diffractive physics: Gluon densities in p & A

- Elastic diffractive: very (VERY) small angle scattered proton:



- Will have to resort to “Roman Pots” to catch these
- For Nuclei, need to learn how to handle nuclear break up:
 - Neutrons in ZDC, protons in Roman Pots, details for ePHENIX need to be studied
 - Recent study for RPs in STAR very encouraging: J. H. Lee in ³He Workshop: See E. Aschenaur or J. Dunlop’s talk



ePHENIX: current thoughts and planning

- sPHENIX promises to be a good (not ideal) first ePHENIX detector for early phase of eRHIC, but lot needs optimization
 - Low mass tracking to replace current sPHENIX plans
 - Central magnet strength 1T \rightarrow 2-3T (cost?)
 - Central solenoid bore 1m \rightarrow 1.5m radius (cost?)
- Evolution of ePHENIX to the eRHIC detector:
 - Replace the remaining muon arm with tracking, PID, EMC, and HCAL in that direction
 - Possibly add HCAL in the central arm?

Over all guiding principle:

- *Physics case for each stage of evolution needs to be compelling*
- *Upgrades for sPHENIX can not be in conflict with future detector requirements for eRHIC*



Generic Detector R&D for an EIC

- Community wide call for R&D Detector proposals for EIC
- Program run from BNL (RHIC R&D funds), NOT site specific

New detector technology for fiber sampling calorimetry for EIC and STAR.

UCLA, Texas A&M, Penn State

Front end readout modules for data acquisition and trigger system.

Jefferson Lab

DIRC based PID for EIC Central Detector.

Catholic U. of America, Old Dominion U., JLab, GSI (Darmstadt)

Liquid scintillator calorimeter for the EIC.

Ohio State U.

Test of improved radiation tolerant silicon PMTs.

Jefferson Lab

Letter of Intent for detector R&D towards an EIC detector (Low mass tracking and PID).

BNL, Florida Inst. Tech., Iowa State, LBNL, LANL, MIT, RBRC, Stony Brook, U. of Virginia, Yale U.

Seeds for possible future experimental collaboration.... Attracting new collaborators.... **Like this group today!**

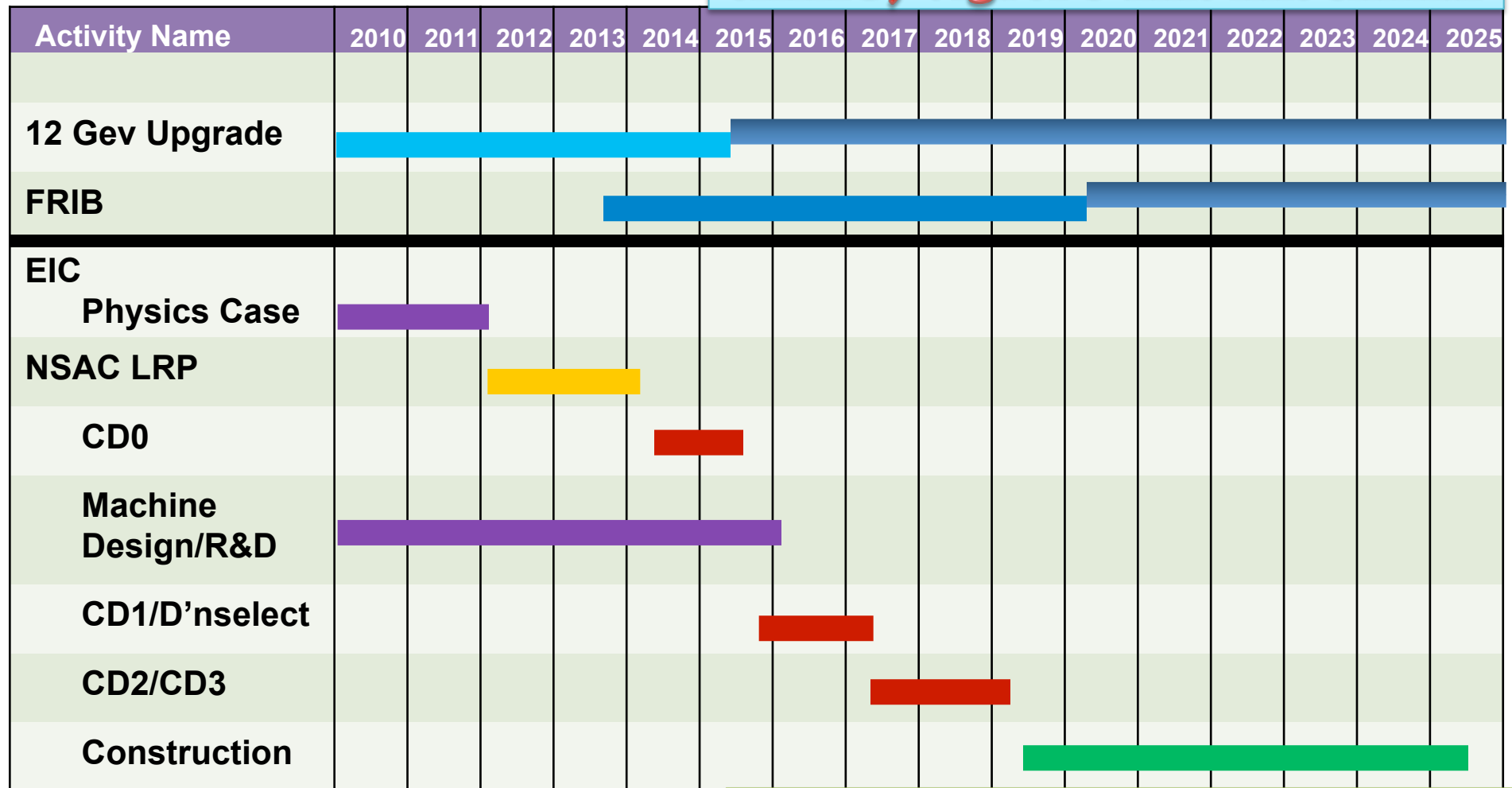
Next round of applications and updates : November, 2011

A new proposal for precision electron beam polarimetry submitted which includes Dr. Frank Maas (GSI/Mainz) as one of the Co-PI. Motivation: precision $\sin^2\Theta_W$ measurement.



EIC Realization Possible Time Line

eRHIC, Vigdor's time line similar



Construction Schedule Highly Site Dependent



Summary

Science Case for EIC: → “Understand QCD” via

“Precision study of the role of gluons & sea quarks in QCD”

The Collaboration & the BNL+Jlab managements are moving (*together*) towards realization: *Milestone: NSAC approval 2013*

- Machine R&D, detector discussions, simulation studies towards making the final case including detailed detector design and cost considerations

INVITATION: Ample opportunities to *get involved and influence* this exciting quest for understanding of QCD!

Possibilities of collaboration seem to exist between GSI and BNL:

Accelerator , Detector and Polarimetry: all crucial for the EIC.